

APPENDIX A

DESIGN EXAMPLES

A-1. Clarification. This design example is based on the following conditions: river water source; no softening required; turbidity of raw water is variable, but rarely exceeds 1,000 units. See plant flow schematic, figure A-1, showing two-stage clarification treatment.

a. Facility to be served. The water treatment plant will serve a permanent installation.

b. Population served.

- Resident 6,000
- Nonresident 1,800
- Effective population = $\frac{1,800}{3} + 6,000 = 6,600$

c. System design capacity.

- Capacity factor: 1.42 (based on effective population)
- Design population = $(1.42)(6,600) = 9,372$
- System design capacity, based on population = $(9,372)(150)$
= 1,405,800 gpd. Use 1.41 mgd = 980 gpm = 2.18 cfs
- Special design capacity for industrial processes,
independently determined: 0.79 mgd
- Total system design capacity = $1.41 + 0.79 = 2.20$ mgd
= 1,530 gpm
= 3.40 cfs

d. Preliminary treatment.

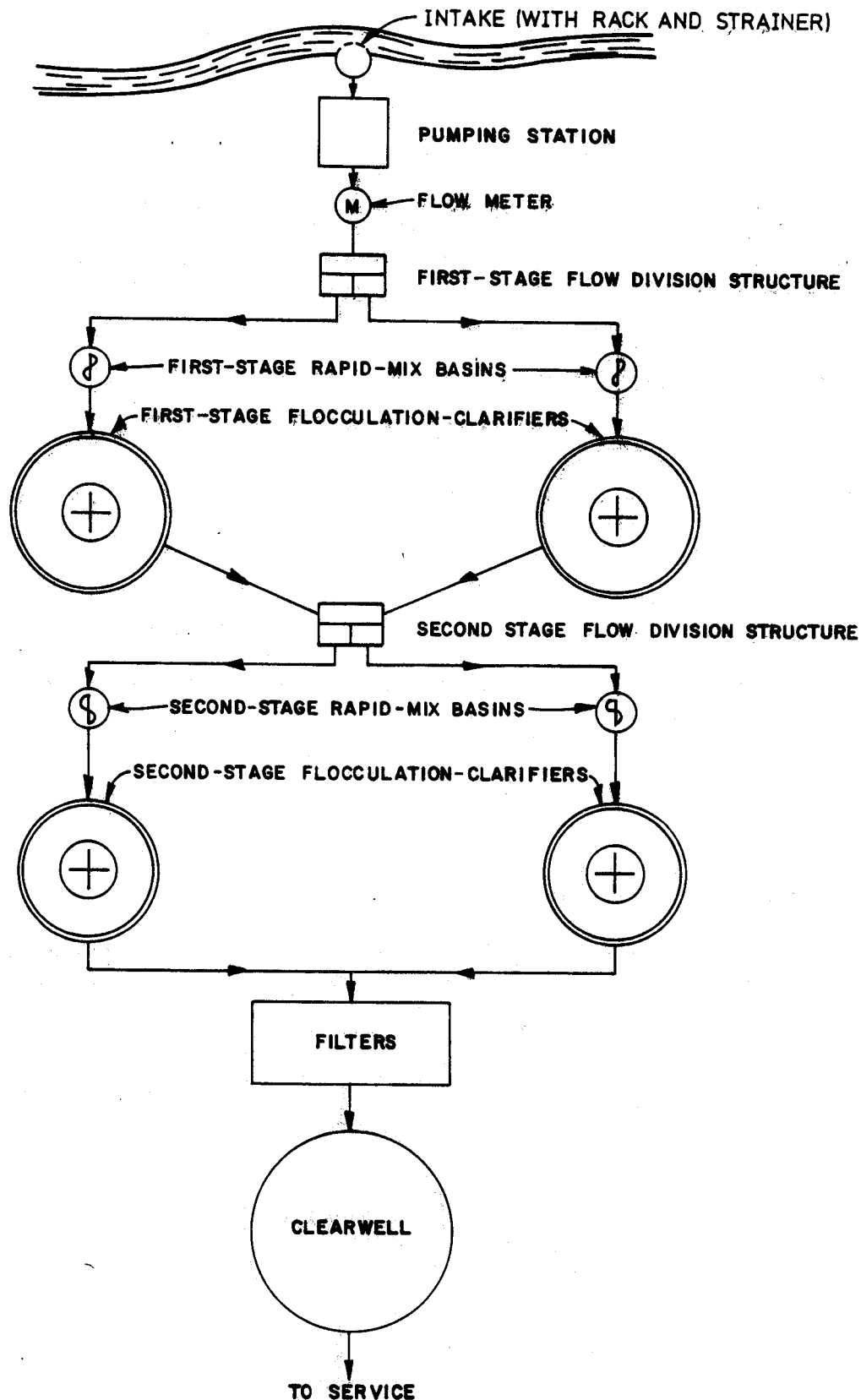
(1) Rack and strainers. Provide coarse rack with 3-inch clear opening followed by hydraulically cleaned basket strainers with 3/8 inch clear openings ahead of each pump. Strainers sized to provide velocity of less than 2 fps through 3/8 inch openings.

(2) Pumps. Provide three pumps rated at 1.10 mgd each. This gives firm pumping capacity of 2.20 mgd. Maximum capacity is 3.30 mgd.

(3) Meter. Provide Venturi-type flow meter in pipeline from intake works to treatment plant. Meter should be sized to cover expected flow range, minimum to maximum. Flow meter should be equipped with flushing lines and bayonet cleaning rods.

(4) Presedimentation basins. Not required.

(5) Aeration. Not required.



U. S. Army Corps of Engineers

FIGURE A-1. FLOW SCHEMATIC WATER CLARIFICATION PLANT

9 Apr 84

(6) Flow division. Normally, flow division is to be maintained through the second stage of treatment. Provide first-stage flow division structure with two identical rectangular weirs which will split flow into two equal parts. Hydraulic design of division structure should be such that flow, corresponding to maximum pumping capacity (3.3 mgd), can be carried through either half. Provide plates or gates so that either half of flow from division structure can be stopped.

e. First-stage mixing and sedimentation.

(1) Rapid mix. Provide two identical rapid-mix basins, each providing a detention time of 20 seconds at 50 percent of design flow. Volume of each basin is $(20)(0.5)(3.4)$ or 34 cubic feet. Provide one electric motor-driven, rapid-mix unit in each basin which will yield a G value of approximately 700/second at a water temperature of 50 degrees F.

(2) Flocculation-sedimentation. Provide two mechanically-equipped, circular flocculator-clarifiers, each sized for 50 percent of design flow. These units will normally operate in parallel.

- Detention time in flocculation zone: 30 minutes.
- Detention time in peripheral sedimentation zone: 3 hours.
- Basin side-water depth: 12 feet.
- Flocculator depth: 10 feet.
- Flocculator volume = $(30)(60)(0.5)(3.4) = 3,060$ cubic feet.
- Flocculator area = $3,060/10 = 306$ square feet.
- Flocculator diameter: 19.7 feet.
- Volume of sedimentation zone: $(3)(60)(60)(0.5)(3.4) = 18,360$ cubic feet.
- For 12 foot basin depth, sedimentation area = 1,530 square feet.
- Total basin area = $306 + 1,530 = 1,836$ square feet.
- Upflow rate in sedimentation zone =

9 Apr 84

$$\frac{(.5)(2.2)(10^6)}{1,530} = 719 \text{ gpd/square foot or } 0.5 \text{ gpm/square foot, a satisfactory value}$$

$$\text{- basin diameter} = \sqrt{\frac{1,836}{\pi/4}} = 48.3 \text{ feet}$$

- Use double, V-notch, effluent weirs with inboard, effluent launder.

- Approximate total weir length, each basin:

$(48.3 - 4.3) (\pi) (2) - 51 = 225$ feet. The 4.3 feet represents twice the distance of the weir from the tank wall. Fifty-one feet is the allowance made for non-effective weir length such as obstructions or supports.

$$\text{- Weir loading} = \frac{(.5)(2.2)(10^6)}{225} = 4,890 \text{ gpd/feet}$$

Flocculator units should have variable speed drives which will yield a G value of approximately 50/second at mid-speed and a water temperature of 50 degrees F. Provide piping and valves so that either basin can be bypassed while maintaining following secondary units in service. Provide basin overflow and basin cover structure if climatic conditions require. Provide basin sludge withdrawal piping to point of sludge disposal. Sludge pumps will be required if gravity sludge flow is not feasible.

f. Second-stage flow division structure. Provide second-stage flow division structure identical to first-stage. This structure allows combining the flows from the two, parallel-operating, first-stage sedimentation units followed by their division into two equal flows, which are then directed to the second-stage rapid-mix basins. Use of this flow-division structure provides maximum flexibility and optimum use of plant facilities when one first- or second-stage rapid mix or flocculator-clarifier is out of service for repair or maintenance.

g. Second stage mixing and sedimentation.

(1) Rapid mix. Provide two second-stage rapid-mix units identical to those used for first-stage rapid mixing.

(2) Flocculation-sedimentation. Provide two mechanically equipped, circular, flocculator-clarifiers identical in size to those used in the first-stage. These units will provide 30 minutes flocculation time and 3 hours sedimentation time. Total time for flocculation, both stages, is 60 minutes. Total sedimentation time, both stages, is 6 hours.

9 Apr 84

h. Filtration. Determine number of filter units.

- $N = 2.7 (Q)^{1/2}$
- $Q = 2.2 \text{ mgd}$
- $N = 2.7 (2.2)^{1/2} = 4 \text{ units}$

Filter configuration will consist of two filters, side by side, along both sides of a gallery sized to accommodate filter piping, valves, controls, etc. Main influent header pipe will be sized for a velocity not to exceed 1.5 fps. Calculated pipe diameter is 20.4 inches. Use 24-inch pipe giving actual velocity of 1.08 fps. Use 12-inch pipes to supply individual filters. At a rate of 2 gpm per square foot, total filtration area required will be $1,530/2$ or 765 square feet or 191 square feet of medium area per filter. Provide 14 feet by 14 feet medium area. Use dual-media filters with 8 inches of filter-grade sand, 4 inches of coarse sand, and 20 inches of filter-grade anthracite, equipped with rotary surface wash capable of producing 0.5 gpm. Actual filter cells, including gullet, will be approximately 14 feet by 18 feet. Use vitrified clay tile or similar underdrains and gravel layer as recommended by manufacturer. Provide rate controllers and filter level control equipment. Establish overall depth of filter cell at 15 feet. Assume an arbitrary operating floor elevation of 15 feet. Significant filter elevations and related depths will be approximately as follows:

	<u>Elevation (feet)</u>
- Filter cell bottom	0.00
- Top of underdrains (plus 10 inches)	0.83
- Top of gravel (plus 10 inches)	1.67
- Top of coarse sand (plus 4 inches)	2.00
- Top of filter sand (plus 8 inches)	2.67
- Top of anthracite (plus 20 inches)	4.33
- Bottom of surface wash equipment (plus 2 inches)	4.50
- Bottom of troughs (plus 14 inches)	5.67
- Operating water level (7 feet above anthracite)	11.33

Depth of water above bottom of filter cell = $11.33 - 0.00 = 11.33$ feet
 Freeboard = $15.00 - 11.33 = 3.67$ feet. All four filters, each operated at 2 gpm per square foot, theoretically will produce

9 Apr 84

(4)(14)(14)(2)(1,440) or 2,257,920 gallons of water in 24 hours. Assuming two filters washed at 15 gpm per square foot for 15 minutes each in each 24-hour period, wash water requirements will be (2)(14)(14)(15)(15) or 88,200 gallons for normal backwash, or about 4 percent of production. Surface washing will require an additional (2)(14)(14)(0.5)(15) or 2,940 gallons. Total downtime, each filter, is assumed to be 20 minutes. The theoretical net water production for delivery to service will be as follows:

- Theoretical total production	2,257,920 gallons
- Loss due to filter down-time	15,680 gallons
- Less wash water required	91,140 gallons
- Net theoretical production available for service	2,151,100 gallons

Under actual operating conditions, with the filter-rate and level control equipment specified, the filters remaining in service will automatically compensate for production lost as a result of a filter being out of service for washing or repair. Level control insures that filter outflow will always match inflow. In addition to flow and level control equipment, provide automatic filter shut-off and alarm equipment to be activated at maximum allowable clearwell level and also provide filter high-level alarm. Provide all essential piping, valves, surface and backwash facilities, and operating consoles. Provide essential instrumentation for each filter. Provide sampling taps for each filter. Plant layout and hydraulic design should be such that additional filters can be readily added as required.

i. Clearwell. Clearwell (filtered water storage) capacity should be related to the available or proposed distribution system storage (ground and elevated). As an approximation for this design example, clearwell capacity of at least 0.6 million gallons could be provided. This is about 25 percent of the plant's daily production when operating at 2.2 mgd (design capacity). Greater clearwell capacity may prove advantageous depending on water demand patterns and plant operating schedule. The clearwell is commonly located adjacent to the filters and at an elevation permitting gravity flow to it. This usually requires an underground structure. An alternative arrangement consists of a sump following the filters, equipped with automatically controlled transfer pumps, which discharge to an above-ground tank or basin. Underground clearwells are commonly constructed of reinforced concrete. For above-ground installations, steel tanks can be used. Regardless of the arrangement, the clearwell should be an independent structure, watertight, and protected against birds, animals, and insects. Vents must be installed and protected against surface and rainwater entry, birds, insects, and animals. A protected,

9 Apr 84

free-discharge, overflow should also be provided. The overflow must not be connected to any sewer or drain. Access to the interior of the clearwell is required. The access opening should be curbed at least 6 inches above the roof surface and be equipped with a hinged, overlapping, watertight, locking cover. As a general rule, the clearwell should be located at least 50 feet from sewers or drains. The area around the clearwell should be fenced and the site graded so that surface drainage is away from the structure. Where winters are severe, special consideration must be given to the design of vents and overflows to prevent freeze-up as a result of vapor condensation. A water level sensing instrument with readout in the plant control center should be provided. This can operate in conjunction with the previously described maximum level control-alarm circulation and lengthened chlorine contact time.

j. Hydraulic profile. The hydraulic interrelationship of major plant units must be carefully considered. In general, the hydraulic design of the plant should be on the side of ample flow capacity so that, under emergency conditions, water can be treated and filtered at considerably more than the normal rate with all filters in service. The approximate elevation data, given in the following tabulation, establish the emergency-operation hydraulic profile:

<u>Location</u>	<u>Elevation (feet)</u>
Water level upstream, first-stage flow division weir	100.00
Water level downstream, first-stage flow division weir	99.00
(Loss: raw water pipe friction + velocity head in pipe	0.42)
Water level in first-stage rapid-mix basin	98.58
(Loss: rapid-mix to first-stage flocculator-clarifier	0.50)
Water level in first-stage flocculator basin	98.08
(Loss: flocculator to sedimentation basin	0.01)
Water level in first-stage sedimentation basin	98.07
First-stage sedimentation basin emergency overflow level	98.57
(Loss: sedimentation basin weirs, launder and piping to second-stage division structure	1.50)
(Loss: second-stage division structure	1.00)
(Loss: division structure to second-stage rapid mix	0.50)

9 Apr 84

<u>Location</u>	<u>Elevation (feet)</u>
Water level in second-stage rapid-mix basin	95.07
(Loss: rapid-mix to second-stage flocculator clarifier	0.50)
Water level in second-stage flocculator	94.57
(Loss: flocculator to sedimentation basin	0.01)
Water level in second-stage sedimentation basin	94.56
Second-stage sedimentation basin emergency overflow level	95.06
(Loss: sedimentation basin weirs, launder and filter influent piping	1.80)
Water level in filters	92.76
Top of anthracite (7.00 feet below filter water level)	85.76
Filter operating floor level (3.67 feet above filter water level)	96.43
(Filter freeboard at second-stage basin overflow level	1.37)
Bottom of filter cells (15.00 feet below filter operating floor level)	81.43
(Maximum loss through filter media, gravel underdrains, effluent piping and controls	10.00)
Maximum water level in clearwell	82.76
(Overall head loss during emergency operation: first-stage division structure - maximum clearwell level	17.24)

By utilizing higher-than-normal chemical dosages, the plant can be operated under emergency overload conditions and still produce water meeting drinking water standards. In deriving the above data, the following emergency conditions were assumed:

(1) All raw water pumps are operated, giving a raw water flow of 3.3 mgd, which is 1.5 times nominal design rate.

(2) Both first- and second-stage rapid mix, flocculation, and sedimentation units on one side of plant are out of service.

9 Apr 84

(3) Reference elevation of water in first-stage flow division structure upstream from flow division weirs is arbitrarily established at the 100 foot mark.

(4) Raw water transmission pipe is assumed to be a flow division structure to first-stage rapid mix with a 44.5 foot, 16-inch pipe having a C value of 100.

(5) Plant units in service:

- Half of first-stage flow division structure.
- First-stage rapid mixer and first-stage flocculator-clarifier.
- Half of second-stage flow division structure.
- Second-stage rapid mixer and second-stage flocculator-clarifier.
- All (4) filters, with filter level control equipment, etc., operating normally.

(6) Filters are to be washed when head loss exceeds approximately 8 feet.

k. Wash water. Water supply for filter backwash can be supplied by a special pump, sized to provide the required flow. If used, backwash pumps should be provided in duplicate. An alternative is an elevated wash water storage tank providing gravity flow. The capacity of this tank should be at least 1.5 times maximum wash water requirement for a single filter. For this example, it is assumed that two filters will be washed in succession, each for 15 minutes, at maximum rate. A water tank having a capacity of three times the wash requirement for a single filter is recommended. Its capacity will be: (3)(15)(14)(14)(15) or 132,000 gallons. The wash water storage tank is refilled by pumping filtered water from the clearwell. Duplicate, automatically-controlled, refill pumps should be provided. A single pump should be capable of refilling the wash water tank in approximately 4 hours. A wash water rate-of-flow controller should be provided on the main wash water line serving the filters. Rate of wash water flow and totalizing instrumentation with readout visible during the washing process should also be provided.

l. Wash water recovery. Filter wash water can be recovered and recirculated through the plant. Solids contained in the wash water are removed in the plant sedimentation basins. Wash water recovery requires the construction of a basin into which the wash water is discharged. The basin bottom should slope steeply toward the suction pipe of the recycling pump. The capacity of the basin should be

9 Apr 84

approximately equal to the value of two, maximum rate, 15-minute filter washes, or about 90,000 gallons. For an assumed schedule of two filter washes every 12 hours, the recycle pump should have a capacity of about 125 gpm so that the recovery tank will be emptied in about 12 hours. The recycle pumps should be provided in duplicate. The recovery tank should be equipped with an overflow and a drain connection, both discharging to the plant waste disposal system. Under unusual circumstances, associated with raw water quality, it may be undesirable to recycle wash water. For such a situation, the wash water can be discharged to the recovery basin and then drained slowly to the plant waste disposal system.

m. Chemical application. Table A-1 summarizes major features of chemical application and related factors.

n. Chemical storage space. Chemical storage space requirements must be analyzed in terms of required application rates, shipping schedules and quantities. In general, a 30-day supply of a given chemical, based on estimated average feed rate, is the minimum storage volume that should be provided. If chemicals are purchased in bulk, the minimum storage volume available should be 150 percent of the volume of one bulk shipment, or about 30 days of storage at average feed rate, whichever is greater. For example, if the chemical purchase contract is for liquid alum, depending on local conditions, the manufacturer may elect to ship as follows: rail tank cars, 7,000 to 10,000 gallons; tank trucks, 3,600, 4,000 or 5,000 gallons. For rail delivery, minimum storage should be $1.5 \times 10,000$ or 15,000 gallons. For tank-truck delivery, minimum storage should be $1.5 \times 5,000$ or 7,500 gallons. If the estimated average alum feed rate is 30 mg/l and the plant is operated at design rate, 2.2 mgd, daily requirements, in terms of dry alum, are $(30)(8.34)(2.2)$ or 550 pounds per day. Liquid alum, as furnished by the manufacturer, normally contains 5.4 pounds of dry alum per gallon of solution. The daily alum solution requirement will, therefore, be about 102 gallons. A storage volume of 15,000 gallons provides about 150 days of storage at average feed rate and design flow rate; a storage volume of 7,500 gallons, about 75 days. In this example, standard shipping volumes determine storage capacity. If the alum supply is to be purchased and stored in 100 pound bags, minimum bag storage space equivalent to $(30)(550)$ or 16,500 pounds of alum should be provided. Loosely-packed, dry alum has a bulk density of about 50 pcf. The minimum bag storage volume should, therefore, be about 330 cubic feet arranged so that bags can be handled and stored on pallets. Suppliers should be consulted in advance of design regarding shipping quantities, schedules, and costs. It may be possible to reduce overall shipping and handling costs by providing plant storage capacity that will permit the manufacturer to ship in larger quantities.

A-2. Iron and manganese removal. Source of raw water - ground water, containing approximately 3.0 mg/l of iron and 0.25 mg/l of manganese.

9 Apr 84

No sulfide present. The pH of the raw well water is 7.5. Laboratory studies have indicated that iron and manganese oxidation and precipitation can be readily accomplished by aeration and chlorination, followed by a short period of flocculation. (Prediction of the performance of an iron-manganese removal treatment plant, based only on the chemical characteristics of the raw water, is difficult due to the variety of factors that can influence the removal processes. For this reason, laboratory and possibly pilot plant tests are desirable prior to the design of the treatment plant.)

a. Facility to be served. The water treatment plant will serve an Army boot camp.

b. Population served.

- Resident 5,200
- Nonresident 3,600
- Effective population = $5,200 + \frac{3,600}{3} = 6,400$

c. System design capacity.

- Capacity factor: 1.43
- Design population = $(1.43)(6,400) = 9,152$
- System design capacity, based on population = $(9,152)(150) = 1,372,800$ gpd. Use 1.37 mgd
- Special design capacity for industrial processes and landscape irrigation: 0.30 mgd
- Total system design capacity: $1.37 + 0.30 = 1.67$ mgd = 1,160 gpm = 2.58 cfs

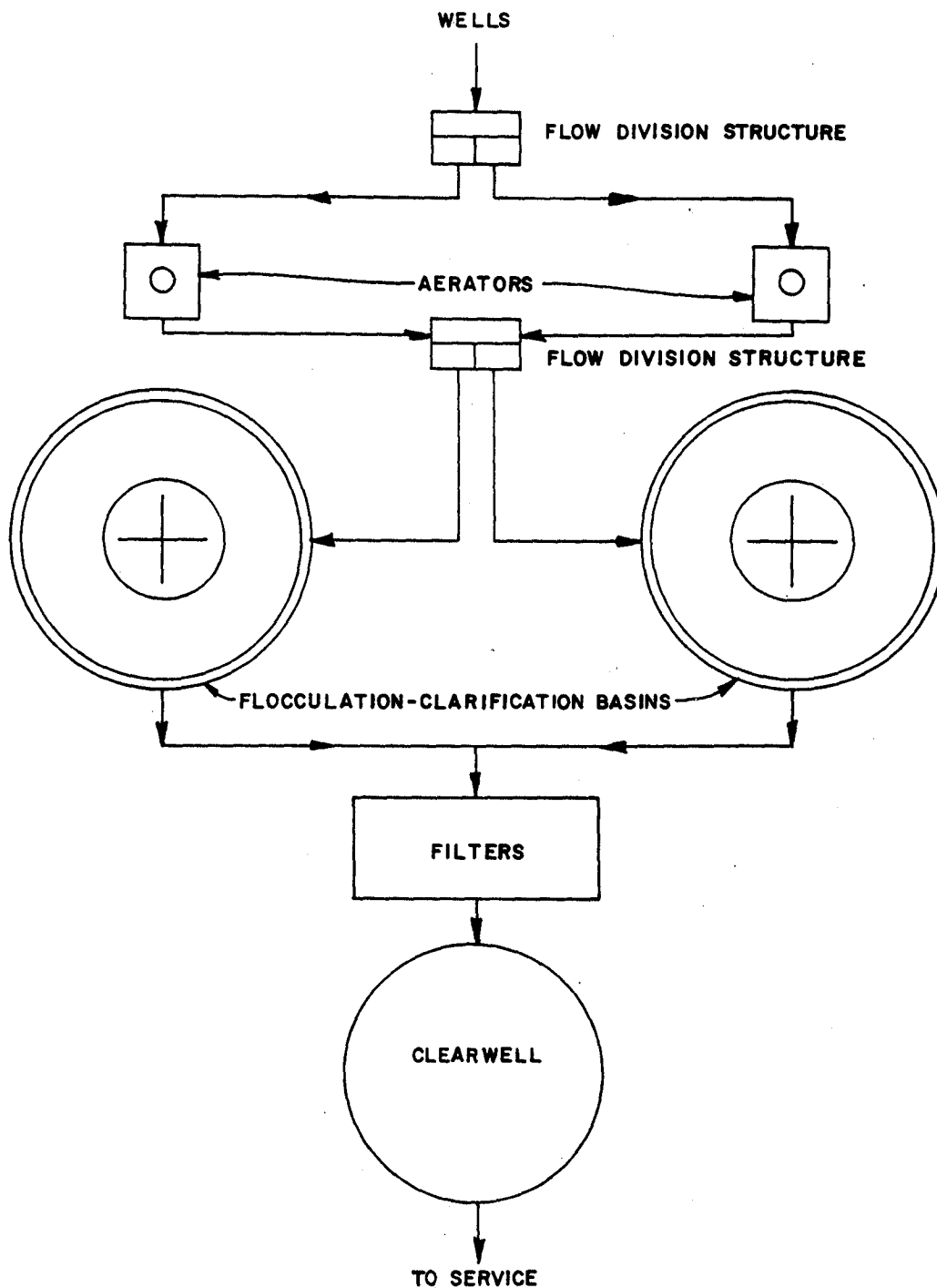
d. Aeration. Provide flow-division structure followed by two natural-draft, multiple-tray aerators. Flow is divided equally between aerators. Each aerator has a distributor tray, three coke trays, and a collector tray, with the coke and collector trays spaced 18 inches apart. Dimensions of trays are 7.5 feet by 7.5 feet. Hydraulic loading is 10 gpm per square foot. Each tray is filled to a depth of 6 inches with 2 inch pieces of coke. The distributor tray orifices are sized and spaced to insure 2 inches of head on the orifices. In a mild climate, aerators can be located outdoors where good, natural ventilation will be obtained. If severe freezing conditions are likely, aerators must be housed and mechanical ventilation provided. Flow-division structure ahead of aerators must be designed so that

9 Apr 84

either aerator can be taken out of service for maintenance while plant continues to operate at full capacity. See figure A-2.

e. Chlorination. Provide two identical solution-type chlorinators, each capable of applying up to 5.0 mg/l of chlorine to the aerated water. For a 5 mg/l dosage, the total daily chlorine requirement will be $(5)(8.34)(1.67)$ or 69.6 pounds of chlorine per day. Apply chlorine to effluents from aerators.

f. Flocculation-sedimentation. Provide flow division structure for aerated water and two identical, circular, flocculator-clarifiers equipped for mechanical flocculation and sludge removal. Flocculator zone, located in center of the basin, should have a detention time of approximately 30 minutes at 50 percent of design flow. Peripheral sedimentation zone should have a detention time of approximately 2 hours, and an upflow rate of approximately 0.75 gpm per square foot (1,080 gpd per square foot). These requirements can be met by a flocculator-clarifier basin with an overall diameter of 36 feet and a side water depth of 12 feet. Clarifier effluent should be collected by means of a weir and launder along the periphery of the basin. Aerator effluent division structure allows either basin to be out of service while utilizing both aerators, or both basins in service while only one aerator is operating. Provide basin overflow piping and sludge withdrawal piping. Provide cover structure for basins if severe freezing conditions are anticipated.



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FIGURE A-2. SCHEMATIC OF IRON AND MANGANESE REMOVAL PLANT

9 Apr 84

Table A-1. Chemical Application

<u>Chemical</u>	<u>Storage</u>	<u>Feed Equipment</u>	<u>Feed Points</u>
Alum ¹	Chemical storage area	Dry	First- and second- stage rapid-mix
	Elevated hopper in chemical feeder room	Dry	
	Tanks in bldg.	Solution	
Ferric sulfate ¹	Chemical storage area	Dry	First- and second-stage rapid-mix basins.
	Elevated hopper in chemical feed room	Dry	
Poly-electro-lyte ²	Chemical storage area	Solution	First-stage rapid-mix basins or Combined filter influent
Chlorine ⁴	Separate ventilated room in chemical feed area	Solution ³	Rapid-mix basins and/or Combined filter influent and/or Combined filter effluent
Potassium perman-ganate	Chemical storage area	Solution	First-stage rapid-mix basins
Activated carbon ⁵	Chemical storage area	Dry	First-stage rapid-mix basins and Combined filter influent

9 Apr 84

Notes:

- 1 Alum (or ferric sulfate), the principal coagulant, and associated feed systems are critical to plant performance and water safety. Therefore standby feeding facilities and ample reserve coagulant storage must be provided.
- 2 Alternative feed points are provided in the interest of treatment flexibility. Normally, polyelectrolyte will be applied at the first-stage rapid-mix basins; but under some raw water quality conditions, it may provide advantageous to feed an additional small quantity, 0.1 mg/l or less, of polyelectrolyte to the combined filter influent. Polyelectrolyte, so applied, acts as a filter aid and improves turbidity removal by the filtration process.
- 3 Chlorine and the chlorine feed systems are critical to the production of safe water. Standby chlorination equipment and ample reserve chlorine storage space must be provided.
- 4 Alternative feed points are provided in the interest of treatment flexibility. Normally, sufficient chlorine will be fed at the second-stage rapid-mix basins to provide a free chlorine residual in the effluent from the filters. The residual is then adjusted upward as necessary by application of a small amount of chlorine to the combined filter effluent. Chlorine will be applied to the combined filter influent only when little or no chlorine residual is present in the sedimentation basin effluents.
- 5 Alternative feed points are provided in the interest of treatment flexibility. Activated carbon will be used on an intermittent basis, as required, for taste-and-odor reduction. When it is necessary to apply large quantities of carbon, it should be applied to the first-stage rapid-mix basins. For some taste-and-odor conditions, the effectiveness of the carbon may be increased by splitting the carbon dosage between the first-stage rapid-mix basins and the combined filter influent. When using a split carbon feed, the bulk of the carbon should be applied to the rapid-mix basins with no more than about 10 percent of the total carbon application going to the combined filter influent. Under these conditions, it probably will be necessary to increase the chlorine dosage to the combined filter effluent in order to provide disinfection and an adequate residual in the water delivered to service.